"IMPROVING THE READING DISTANCE OF OMNIDIRECTIONAL TRANSPONDER-BASED SYSTEMS".

BONI ANGELO
is electronic design responsible at MED S.p.A., a company involved in the design of high technology security access systems and anti-theft devices, especially for cars and trucks. He holds 15 patents in the electronic field.

MASSIMO MONTECCHI
is R&D engineer at MED S.pA. He holds 2 patents in the electronic field.

Abstract

Low frequency transponder-based systems (≈125 KHz) use the electromagnetic field generated by a transmitting coil to energise (via a small receiving coil) the I.C. contained in the transponder. That I.C. modulates the field by absorption, sending back an identification code. The system is very simple and useful, because the transponder don't need any battery to operate. Unfortunately, when the distance increase, the field modulation index is very low, on the order of $1 \cdot 10^{-5}$ at the maximum distance, and hence difficult to detect. The authors describe the problems encountered in designing a "maximum distance" transponder reader system, and their practical solutions. Another problem with transponder-based systems is the omnidirectionality: since the antennas are coils, they exhibit strong directionality, with null points and null planes.

BASIC APPLICATIONS AND OPERATING PRINCIPLES

Transponder based systems are used to transmit wireless informations between a fixed module (usually) and a portable one. Reading distance can range from few millimetres to several metres, depending on applications and technologies (Fig.1).

Applications spans from contactless credit card, animal identification, parking access control, security access and personnel identification, anti-theft for cars and trucks, industrial process tracing, container identification, luggage and goods management, merchandise protection, etc.

Transponder's dimensions range from glass tube type, with a diameter of 2 mm and a length of 16 mm, typically for animal implantation, to credit-card size for people access control, and to 10x10x5 cm or more for long range types, mainly for cars access control or industrial processes tracing.

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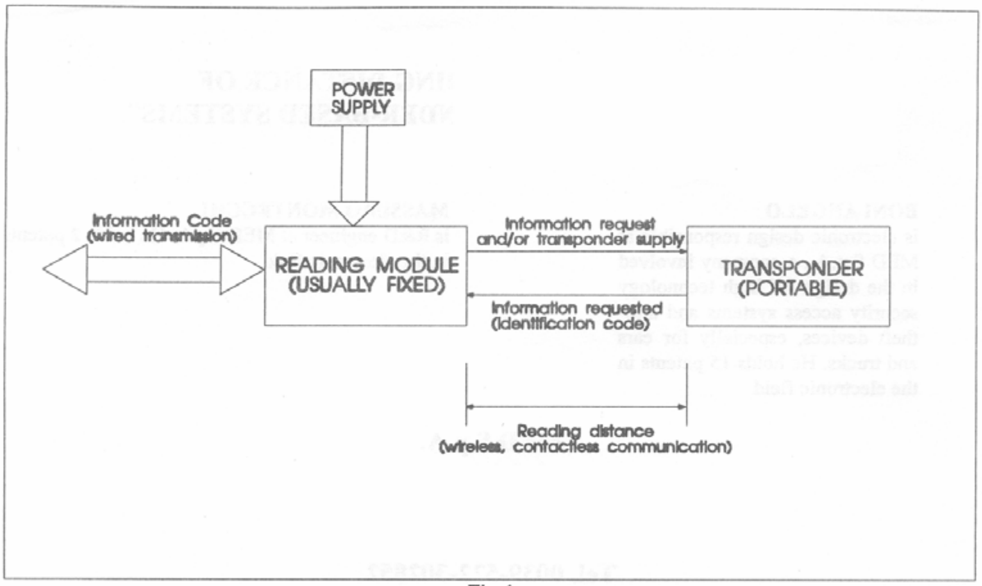

Fig.1

Several intermediate dimensions are available, such as bigger glass tubes or disc types, ranging from 1 cm diameter and 2 mm thickness to 10 or more cm diameter. Different technologies are used to cover the broad spectrum of applications in which transponders are employed: for example luggage identification requires a very low cost transponder ($1 or less), in high run production, with a reading distance in the order of 20-50 cm. Vehicle identification and parking access control, instead, require a reading distance of at least 1 or 2 metres, and transponder's cost can be in the $10 to $100 range. Transponder reading units can range widely in price and dimensions, depending on reading distance and number of users. Intelligence capability of the reading units can also range widely, from a simple gateway function between transponder and the rest of the system, or, especially for small systems, to a stand alone access control unit.

Automotive security, for example, demand a small, low cost central unit ($5 to $20) which is able to handle 2 to 4 transponders.

BRIEF SURVEY ON TRANSPONDER TECHNOLOGIES

LOW FREQUENCY TRANSPONDERS

They operate typically in the 125 KHz frequency band and use magnetic antennas to transmit and receive data. They can be self powered by the 125 KHz carrier or battery powered, and can be very small and very low-priced. This technology is the most diffused at the moment.

MICROWAVE TRANSPONDERS

They operate in the GHz range of the R.F. spectrum and are usually bigger than their low frequency counterparts, although they exhibit a longer reading distance. At the moment this technology is more expensive (especially from the central unit side) and is not very diffused.

ACTIVE TRANSPONDERS

Active transponders are biased by an internal battery to supply power to an internal microprocessor (or to a special purpose control I.C.). The central unit sends a (usually coded) interrogation request. The transponder answers, sinking power from the battery, for example by activation of an internal R.F. transmitter. They generally exhibit a very good reading distance that does not change in dependence of transponder operation (reading or writing data). They are

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however bigger and more expensive than their passive counterparts. Reliability is strongly related to battery life and hence to low power circuitry and immunity to parasitic activation by electromagnetic noise. Commercial transponders, with battery life in excess of 10 years, are common.

PASSIVE TRANSPONDERS

The electromagnetic energy associated with the carrier wave transmitted by the central unit is extracted by the transponder and used as a power source. Three different principles are used to answer to the central unit:

1. Amplitude modulation of the transmitted carrier by magnetic field absorption.
2. Bidirectional communication using different frequencies for transmission and answer.
3. Transponder temporary storing of the received energy into a capacitor. Coded data are sent back, at the end of an interrogation request, using the energy previously stored.

In Fig 2 a brief table of transponder's performance vs. technology is given.

TRANSPONDER TYPE	DIMENSIONS	COST	READING DISTANCE	READING RELIABILITY	REMARKS
Low frequency, passive, read only	Very small: from Ø 1.6 x 16 mm, to several cm	Very low	Short / Medium short	Excellent	• Very good, very diffused. • Can be fully integrated in a single chip.
Low frequency, passive, read/write	Very small: from Ø 2.3 x 16 mm, to several cm	Low	Short	Excellent	• The writing distance is lower than the reading distance.
Low frequency, active, read/write	Medium: in the few cm range	Medium	Medium / Long (few meters)	Good to poor (depending on electronic circuitry)	• The writing distance is equal to the reading dis-tance. • Intelligence and large memory capabilities
Microwaves, passive, read-only	Medium and Large	•Transponder: medium • Central unit: high	Medium / Long (few meters)	Good	• Microwaves power need can be excessive.
Microwaves, passive, read/write	Medium and Large	High	Medium / Long (few meters)	Good	• Microwaves power need can be excessive
Microwaves, active, read/write	Medium and Large	High	Long	Good to poor (depending on electronic circuitry)	• Very complex system

Fig. 2

THE ABSORPTION BASED SELF FEEDED TRANSPONDER

The design goals were to obtain a transponder access system to be used in MED's anti theft devices with the following characteristics:

- reading distance: at least 20 cm, <u>omnidirectional</u>
- receiving antenna: ferrite coil Ø 6x30 mm max.
- transmitting antenna: 70x50x15 mm
- operating temperature: -40°C to +85°C
- stand by current: less than 5 mA.

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Two different technologies were tried: the low frequency passive, and the low frequency active.

The second approach gave us, of course, a great advantage in terms of reading distance improvement, but on the other hand there are higher costs, greater dimensions and poor reliability (due to battery dependence). In any case, the MED's low frequency active transponder system generated good results, since the system operated at a distance of over 1 meter with very small receiving and transmitting coils, and a stand by current in the μA range (assuring a battery life more than 10 years long). Furthermore, a MED patented circuit configuration provided to the system a reduced operation capability in case of battery failure, assuring a distance range from 5 to 10 cm.

Even if the active transponder system was a good starting point it was decided to proceed with the passive transponder approach, in order to decrease size and costs.

Two were the main problems to overcome for obtaining a good, omnidirectional reading distance:

1. Since both the reading and the transmitting coils are very small it was necessary to dramatically improve the signal-to-noise ratio.
2. The antennas radiation pattern was characterised by null points and also null planes, which in fact tend to decrease the overall system sensitivity more than one order of magnitude (Fig.3).

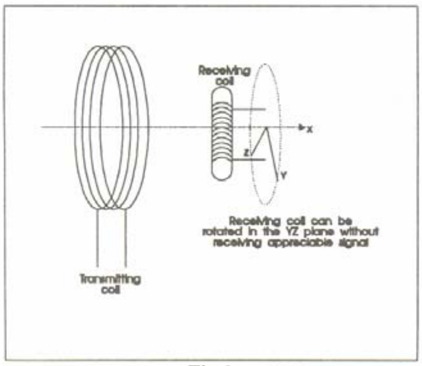

Fig.3

Before the description of the methods adopted to improve the reading distance, a brief explanation of the basic principles related to the absorption-type self feeded transponder is given (Fig.4).

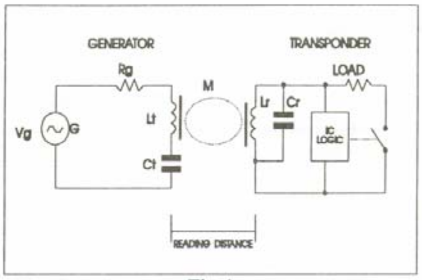

Fig.4

The sinusoidal generator G feed the resonant circuit Ct, Lt, with a signal:

$$A = \sin\omega t \qquad (1)$$

with $\omega = 2\pi f$, f typically 125KHz

The maximum current flowing into the resonant circuit, considering ideal (lossless) components, is given by:

$$I = \frac{Vg}{Rg} \quad , \qquad (2)$$

being Rg the source resistance. From equation (2) it can be seen that the main limiting factor for the current flowing is Rg.

Lt is an open magnetic circuit inductor and hence it radiates a magnetic field in the space.

A small part of that field is picked up by the Lr coil, which also resonates with its Cr capacitor at the generator's frequency. If the voltage amplitude induced across Lr is in the order of 3 to 4 volts, the logic I.C. will start to operate, controlling an internal switch that open and close at the code rate. The net result is to connect and disconnect a load to the parallel resonant Lr,Cr circuit so that the magnetic field is modulated accordingly (scope waveforms plot of Fig.5).

This modulated field is seen, by the transmitting Lt coil, as a difference in energy absorption, and hence in an amplitude modulation superimposed to the generator's sinusoidal wave. The modulation index is very small because the mutual inductance "M" between the two magnetic circuits is barely measurable: at the maximum reading distance M can be estimated in the 10^{-5} to 10^{-6} range.

Two factors are crucial in determining the maximum reading distance (provided that

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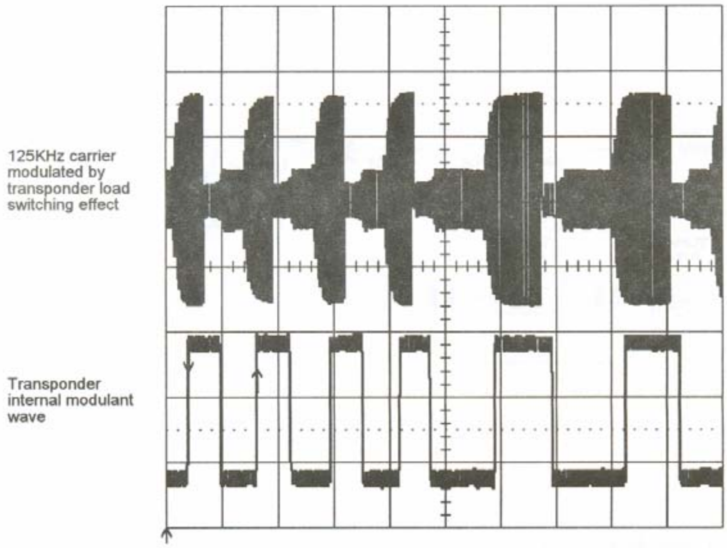

Fig.5

geometries of transmitting and receiving coils are kept constants):

1) The maximum distance at which the transmitting coil Lt is able to generate a field strong enough to activate the logic I.C. in the transponder.

2) The maximum distance at which the modulated field received by Lt is detected with a suitable signal to noise ratio.

Point 1) may be a limiting factor in certain countries, where those systems must meet more stringent regulations in terms of maximum radiated energy, thus limiting the maximum emitted power.

Point 2) is a function of the system's capability of being low noise in the emitter and in the detector circuitry. In Fig.6 is showed a block diagram of the system as implemented in the MED's product.

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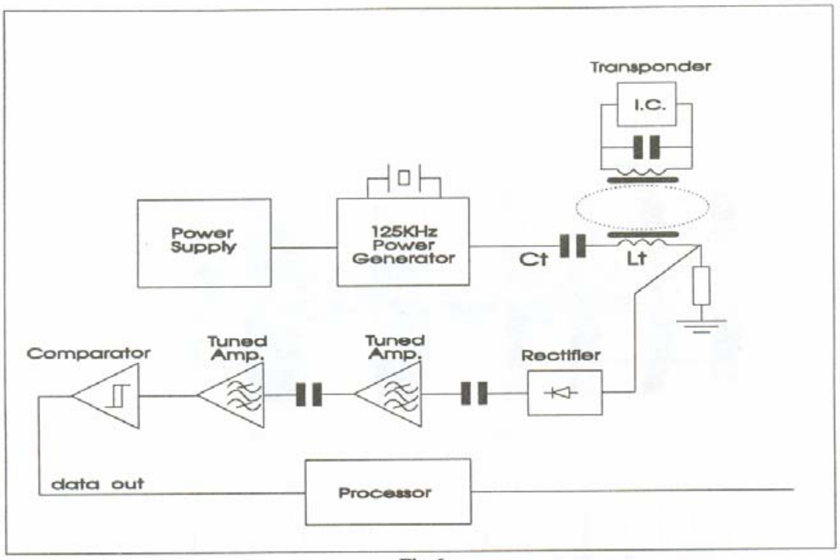

Fig.6

Following, a brief description of each block and its contribute to the overall noise is given.

A) POWER SUPPLY: the 125KHz sinusoidal wave power generator is feeded by that stabilized supply circuit, and hence its internal noise is fully superimposed to the transmitted signal, thus generating AM noise. Since the detected signal is also an AM modulation (being the modulation index in the order of 10^{-5} to 10^{-6}), the power supply's internal noise should be at least three times less, almost in the frequency band of the transmitted data code. As an example, for a 10Vdc power supply, this translates to a noise not greater than 3 to 30 µV!

B) 125KHz POWER GENERATOR: the emitted carrier signal must be kept clean and with a low residual FM noise. In fact FM noise is translated, by the Lt,Ct series tuned circuit, into AM noise, as can be understood looking at Fig.7.

C) The resonant circuit Lt,Ct should exhibit a good electrical and mechanical stability, to avoid any related mechanical vibration noise.

D) Tuned circuits: the first stage is very similar to a standard receiver's first stage: it should be characterised by low noise figure and high gain. The bandwidth of the whole circuit is related to the bandwidth of the transmitted data.

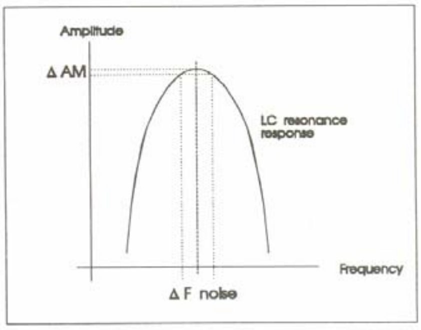

Fig.7

E) Rectifier: noise contribution is negligible: at least one block that isn't critical!

F) Microprocessor: clever software algorithms can help, at the maximum reading distance, to regenerate the correct transponder's data code, and hence help to increase the system reliability.

Thanks to the optimisation process applied to each block we have been able to improve the reading

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distance from the initial 20cm to 32cm, as shown in Fig.8. Considering that the magnetic field decreases with the square of the distance, the real improvement factor must be calculated as:

$$1: (32/20)^2 = 1 : 2.54 . \qquad (3)$$

ANTENNAS DIRECTIVITY

The maximum reading distance of a transponder-based system, as shown in Fig.8, represent of course a best case if both the coil's magnetic axis are coplanar and oriented for maximum flux transfer.

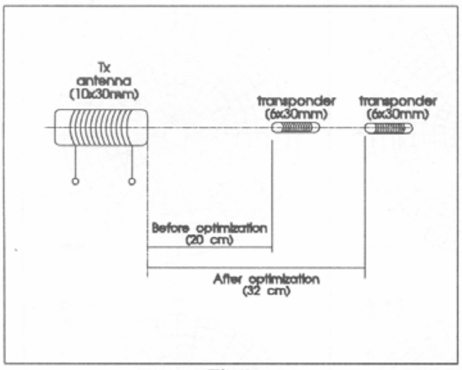

Fig.8

Nevertheless practical applications are far different from the ideal one. In the most general case the transponder axial direction can assume any angle to respect to the transmitter coil. A set of measurements were carried out to plot a sort of polar directivity diagram of the system in real conditions. Results are reported in Fig.9, which points out the reference orientation angles, and in Graphs 1 to 12 added in the next page.

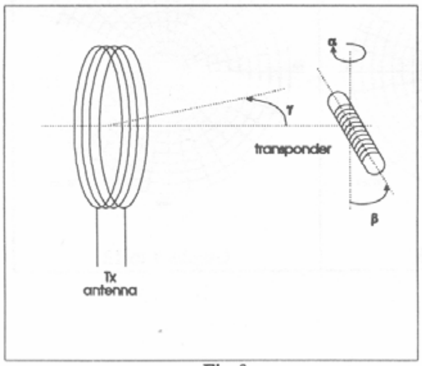

Fig.9

It can be seen that the system exhibit some null points and null planes which cannot be accepted, expecially in a MED product.

The null cancellation possibilities are essentially two:

A) Cancellation obtained by coil motion.

B) Cancellation by means of tridimensional geometry.

CANCELLATION BY MOTION

Cancellation by motion is the more natural way to avoid null points in receiving coded data from a transponder. For example, in people access control systems the person carrying the transponder is walking parallel to the antenna coil.

The null point (see Fig.10) occurs only when the transponder is at the centre of the transmitting coil axis. Unfortunately in MED's applications there is no motion between the transponder and the transmitting coil.

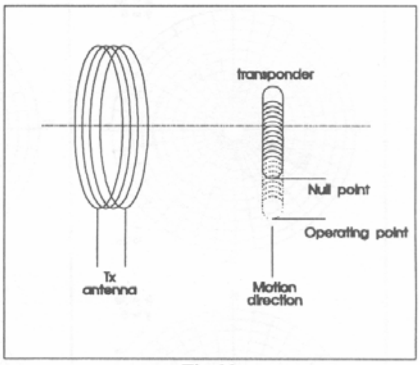

Fig.10

CANCELLATION BY GEOMETRY

Tridimensional geometry give the most reliable solution to the null points problem. Using three transmitting coils, oriented on the three axis X,Y,Z of the space, there is no virtually a null point. It must be pointed out that the coils can't be operated simultaneously, otherwise destructive interference can occur, being the magnetic field a vectorial entity.

The main problem, adopting a three coils antenna, is to realise a clever circuitry to be able to switch the magnetic energy from one coil to the other as quick as possible, and without an excessive cost and

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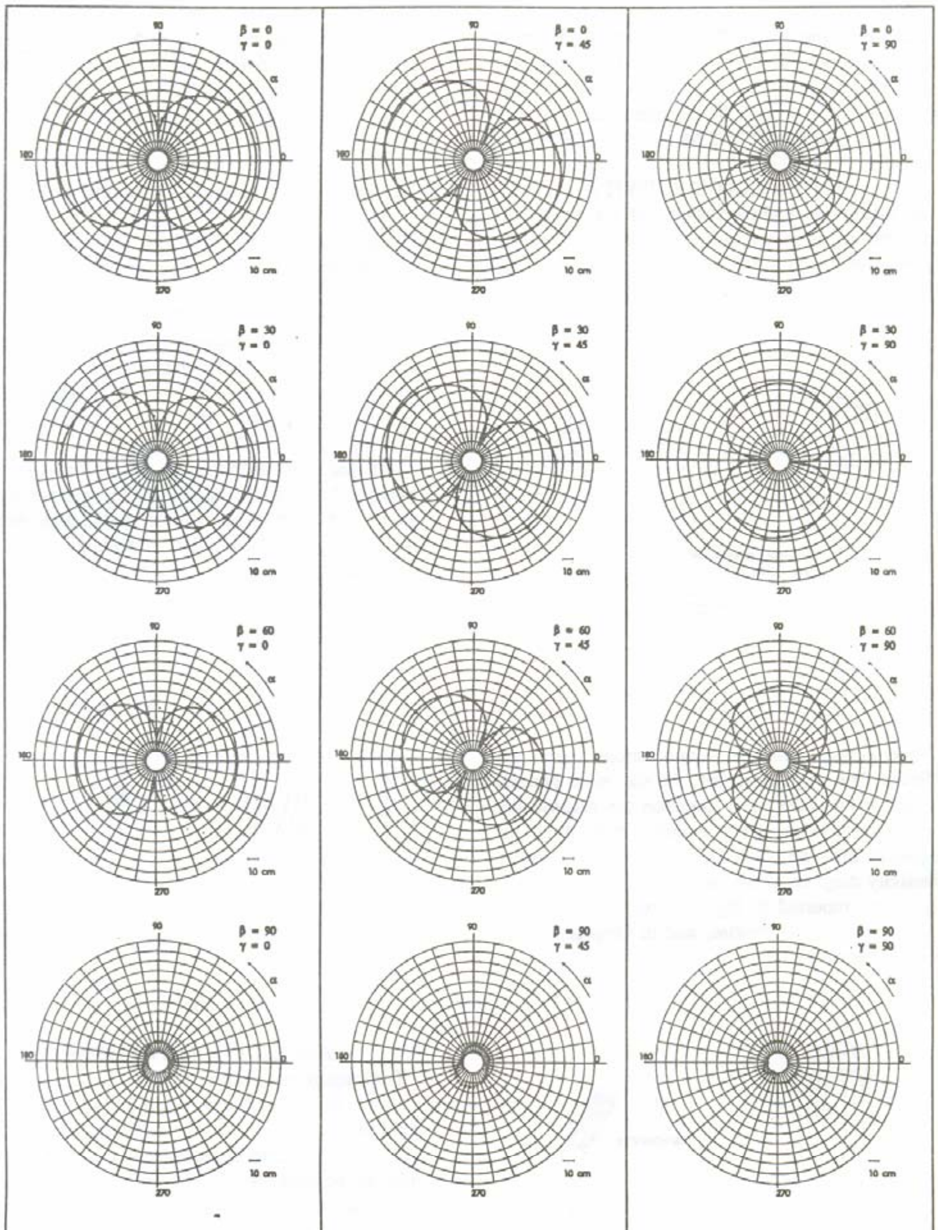

Graphs 1 to 4 — Graphs 5 to 8 — Graphs 9 to 12

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dimension increase. About the dimensions the right idea was to use two ferrite coils and one air wounded coil (Fig.11). This disposition does not increase excessively the antenna dimensions, in particular under a thickness point of view, and permitted very good performances. The system has been patented.

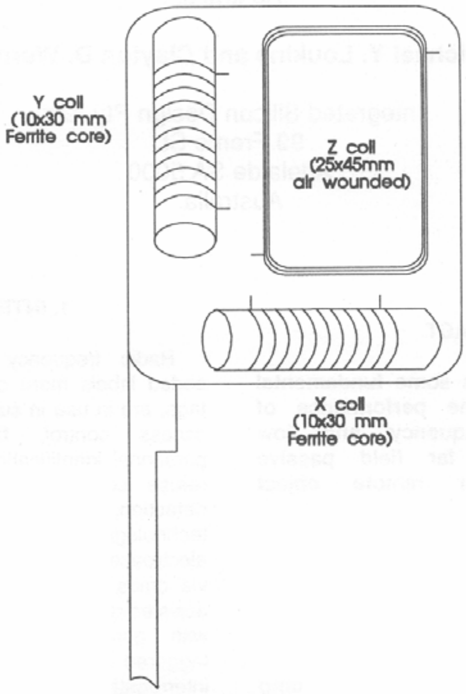

Fig.11

RESULTS

Clever design of the transponder-based system permitted reliable operation. A transponder based access system made in MED, named "PRO30", is part of an immobilizer system for cars and trucks, and is able of doing sure identification of a transponder at a distance in excess of 20 cm, aside from receiving and transmitting coil orientation. Since the PRO30 system is designed for after-market installation, the omnidirectionality is mandatory. In fact, if the transponder must be added to the customer's key holder, the transmitting to receiving coils position is not known (it depends on antenna installation, transponder placement, and ignition key lock position in the car).

The three-coils approach used on the antenna, oriented along the X,Y,Z axis and feeded not simultaneously, allows a compact solution of null point problems. Optimisation of each circuit's block for low noise operation permitted to further increase the reading range while keeping the antenna dimensions unaltered.

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